A Multi-Resolution Approach to Global Ocean Modeling

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The Model for Prediction Across Scales-Ocean (MPAS-Ocean) is a new global ocean model capable of using enhanced resolution in selected regions of the ocean domain. Two simulations are presented to evaluate the model: a uniform high-resolution (15 km) mesh; and a second grid with similarly high resolution (15 km) in the North Atlantic, but coarse resolution elsewhere. Comparisons with observational data show that currents and mesoscale eddy activity are well simulated in both structure and amplitude. Simulations using the variable-resolution second grid are essentially identical to the uniform case within the North Atlantic region. The overall conclusion is that this ocean model is a viable candidate for multi-resolution simulations of the global ocean system on climate-change time scales.

Over the relatively short history of global ocean modeling, the approach has been almost entirely based in structured meshes, conforming quadrilaterals, and a desire to obtain quasi-uniform resolution. This approach has the advantage that numerical schemes and data analysis are straightforward. The disadvantage is that resolution must be nearly uniform across the globe, and doubling resolution requires an additional factor of ten in computational resources.

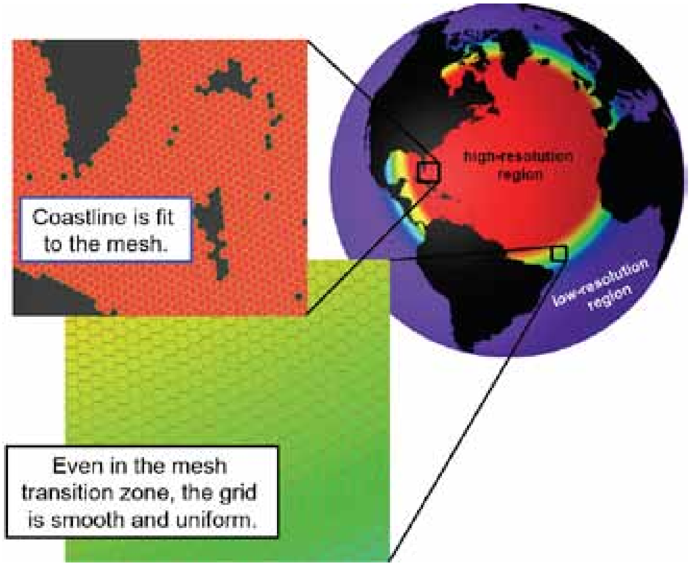

Fig. 1. The x5.NA.15km mesh includes a high-resolution North Atlantic region with 15-km grid cells, 75-km grid cells on the rest of the globe, and a smooth transition zone between them.

Here we present a new ocean model, MPAS-Ocean, developed by the Climate, Ocean, and Sea Ice Modeling (COSIM) team at LANL. Horizontal meshes are unstructured so that high-resolution regions may be embedded within a lower-resolution global mesh. This means high-resolution regional simulations may be performed at a lower computational cost, but the global simulation still supplies realistic currents and water properties from the low-resolution regions. The global meshes, created using Spherical Centroidal Voronoi Tesselations [1,2], vary smoothly from low to high-resolution regions (Fig. 1). Numerical algorithms specifically designed for these grids guarantee that mass, tracers, potential vorticity, and energy are conserved [3,4].

In order to showcase the regional modeling capability of MPAS-Ocean, we present two simulations [5]: (1) x1-15km, a global quasi-uniform mesh where gridcell width is about 15 km; and (2) x5-NA-15km, a variable-resolution mesh with 15-km gridcells in the North Atlantic and 75 km elsewhere (Fig. 1). A snapshot of kinetic energy for x1-15km (Fig. 2) shows many realistic features: Aguhlas rings in the South Atlantic, a strong equatorial undercurrent in the Pacific, vortex ring shedding in the region off west Australia, tropical instability waves, and an Atlantic equatorial undercurrent that is fed via retroflection of the north Brazil current, which periodically sheds coastally trapped rings that propagate into the Caribbean.

A number of quantitative comparisons between observations and the simulations show very good agreement [5]. Because the ocean is a chaotic system, comparisons must be made of decadally averaged climatological variables. Global observations of sea surface height (SSH) mean and variability are available from satellite altimetry and satellite gravity-recovery data sets. All the large-scale features of global ocean circulation are present in the simulations, with similar structure and amplitudes (Fig. 3).

Volume transport across specific cross-sections of the ocean have been observed by shipboard cruises. Decadal averages of these same sections in the simulations show similar ranges as the observations, and some key through-flows, like the Drake Passage, agree within 10% [5]. Cross-sections of the equatorial undercurrent in the tropical Pacific and the Deep Western Boundary Current east of the Bahamas show very good agreement between time-averaged observations and simulations.

An important component of this study is the comparison between the global uniform-resolution and regional variable-resolution simulations. For the North Atlantic region, mean SSH and SSH variability are nearly identical (Fig. 3), and transports through Caribbean passages are within

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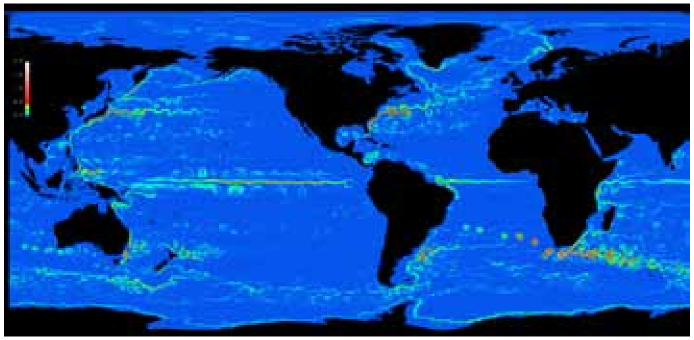

Fig. 2. A snapshot of kinetic energy at a depth of 100 m for the x1-15km simulation. The color scale saturates at red where instantaneous velocities reach 1.0 m/s.

10–20% [5]. This shows that specific regions of the global ocean system can be accurately simulated with local mesh refinement.

Efficiency and scaling on high-performance computers with thousands of processors is an important design consideration for MPAS-Ocean. The x1-15km achieves two simulated years per wall-clock day on 3000 processors on Mustang, a large cluster at LANL. This is the same speed as high-resolution 0.1-degree POP simulations, a long-standing structured global ocean model. The MPAS-Ocean code is designed for scalability and porting to advanced heterogeneous architectures.

The MPAS-Ocean development team has adopted software engineering practices to ensure high-quality code. All projects begin with a requirements and design document, which is reviewed by the team before coding begins. Each new code branch is reviewed and tested by another team member before merging back to the trunk. In addition, a set of standard, automated test cases have been developed to ensure that the code meets design requirements.

One of the challenges of variable-resolution climate modeling is to ensure that turbulence closures and parameterizations are well implemented across scales. COSIM scientists are developing scale-aware parameterizations [6] that will benefit all modeling efforts with methods that reduce the need for tuning parameters for a particular grid scale.

MPAS-Ocean is one component within the MPAS framework of climate models that is developed in cooperation between LANL and the National Center for Atmospheric Research (NCAR). Other MPAS components include land-ice and sea-ice, both under development by the COSIM team at LANL, and atmospheric components created by NCAR. In the coming years, these components will be coupled within the Climate Earth System Model (CESM) to explore research questions surrounding anthropogenic climate change. For the first time, variable-resolution-coupled models of the atmosphere, ocean, sea-ice, and land-ice will be available to study the impacts of climate change on specific regions at very high resolution.

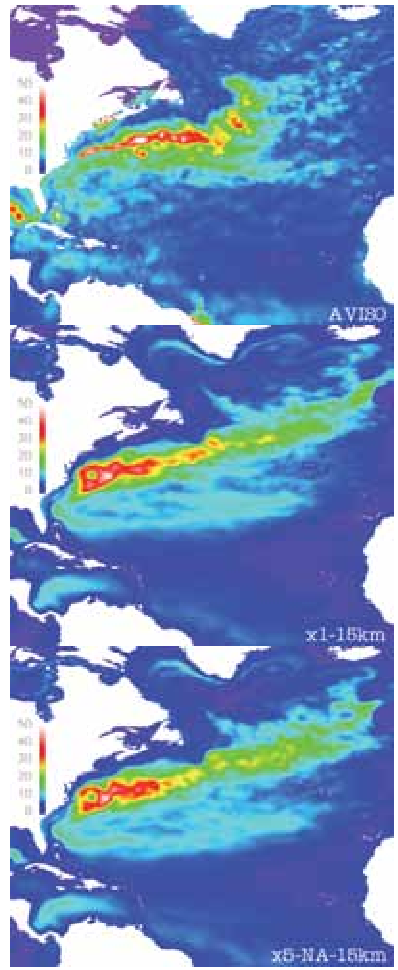

Fig. 3. Sea surface height variability in the North Atlantic from observations (top), the globally uniform mesh (x1-15km, middle), and the North Atlantic regional simulation (x1-NA-15km, bottom). All panels use the same color scheme ranging from 0 cm to 50 cm.

[1] Ringler, T. et al., *Ocean Dynam* **58**, 475 (2008).

[2] Ringler, T. et al., *Mon Weather Rev* **139**, 3348 (2011).

[3] Thubern, J. et al., *J Comput Phys* **228**, 8321 (2009).

[4] Ringler, T. et al., *J Comput Phys* **229**, 3065 (2010).

[5] Ringler, T. et al., "A Multi-Resouktion Approach to Global Ocean Modeling." *Ocean Model*, in press (2013).

[6] Chen, Q. and T. Ringler, *ADTSC Science Highlights*, 36, (2013)